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VIDEO PROCESSING FOR TARGET EXTRACTION, RECOGNITION, AND TRACKING

FINAL REPORT

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This report summarizes the results of a three-year research effort undertaken by the School of Electrical Engineering and the School of Aeronautical and Astronautical Engineering at Purdue University. The purpose of this work has been to investigate various aspects of target recognition and recognition in video data, and tracking of these targets in sequential imagery. The most significant results are in the area of tracking maneuvering targets, using attitude measurements and in the extraction of attitude information from video data. Additonal results are described in the area of partial shape recognition,

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20. ABSTRACT CONTINUED

recognition from range data, and image segmentation.

Foreword

This final report summarizes the results of a three year research effort undertaken by the School of Electrical Engineering and the School of Aeronautical and Astronautical Engineering at Purdue University. The primary purpose of this work has been to investigate the various aspects of target extraction and recognition in video data, and tracking of these targets in sequential imagery. As indicated in detail in Section III, four Ph.D theses and three M.S. theses resulted from this research, as well as 30 additional publications. The authors are indebted to the 12 graduate students listed in Section III who provided the programming and many of the good ideas presented in these publications.

It is gratifying to know that the results of this research will not culminate in only a report. This research has been directly supported by the army laboratories and many trips have been made between Purdue University and Picatinny Arsenal to install and test software and to make comparisons with existing algorithms. Additional contracts have been spawned by this basic research contract which have resulted in more detailed and specific tests and implementations.

The authors would like to thank Dr. Frank Kuhl of the U. S. Army ARDEC and Mr. William Cadwallender also of ARDEC for their interest, support, and research contributions to this project. We also express our appreciation to Dr. William Sander of the U. S. Army Research Office for his support and assistance.

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I. Statement of the Problem Studied

The research problems studied during this research contract emphasized certain sections of the original proposal due to funding limitations. The fundamental research problem addressed was that of extracting useful target information from video imagery and providing estimates of the target's future position. Video processing methods are used to provide estimates of an aircraft's orientation in space. The three orientation angles can be used in a target tracker to improve tracking performance. Advanced trackers of this type utilize a mathematical model of the force system on the aircraft that is a function of vehicle attitude and velocity. Target aircraft do not fly in straight lines during tactical situations. Rather, they will accelerate in a violent, time-varying fashion (i.e., jink) to avoid being shot down. The advantage of jinking is that the future trajectory of the vehicle becomes more difficult to predict, making computation of the gun lead angle substantially less accurate. Lead times of 1 to 4 seconds are typical and during this period an aircraft can maneuver away from tracker gun fire. Orientation was found to be useful in tracking because when a vehicle is going to turn, the first thing that happens is the orientation changes. This has the effect of tilting the lift or thrust vector that acts on the vehicle and the vehicle trajectory turns under the influence of this new force system. Because orientation always leads trajectory changes, orientation is useful in determining where the vehicle is going in the future; i.e., in predicting future trajectories.

Thus two primary research areas were addressed: image processing necessary to derive recognition and orientation in video data, and tracking algorithms which utilize the orientation information. Work in image processing was based on previous efforts which had been developed for recognition of low noise complete contours in image data. Research in this project has emphasized images which contain more difficult imagery either due to noise, resolution, or lack of contrast with the background. The areas of segmentation, partial shape recognition, and recognition of range map data have been studied. Other related image processing research topics were addressed during the course of this project. These include image compression, precision measurements in images, and the use of image morphology processing. One general purpose of this project has been to develop and provide software for research and development in tactical target recognition. The software has been developed on a Sun 4/280 system but has been modified to run on various Unix systems.

Two new classes of target trackers have been developed, one for fixed wing aircraft and one for helicopters. Both new trackers use orientation data in order to substantially improve the accuracy of target trajectory predictions. Specifically, an extended nonlinear kalman filter has been designed that uses radar position and velocity information and optical attitude measurements of the aircraft being tracked.

II. Summary of the Most Important Results

A. Partial Shape Recognition

This research effort involved recognizing a shape when part of the boundary is incorrect due to obscuration or poor segmentation. The first method involves segmenting a contour into pieces based on the breakpoints generated by a polygonal line fit, and describing each segment with Fourier descriptors. When two contours are to be compared, the distances between each of their respective segment sets may be viewed as an inter-segment distance table. Emphasis was placed on the use of dynamic programming techniques to find a subset of shape features along a contour which match a subset of those in a library shape, independent of translation, rotation, and scale of the shape. Special attention was paid to the effects of noise on this technique and modifications which can be made to make the technique less sensitive to noise and resolution changes. The dynamic programming approach developed for this problem finds a path through the distance table which gives the best local matches independent of any few bad matches along the path. Thus the normal dynamic programming approach which results in a global optimum path has been modified to find a large number of local optimums independent of whether it results in a global optimum. Tests on partial aircraft contours and other shapes have shown that this method works very well. The method is described in the Ph.D. thesis by John Gorman [2] and in the IEEE Transaction paper by Gorman, Mitchell, and Kuhl [21].

A demonstration was implemented which allows a TV camera to image various aircraft scale models. The data is digitized and aircraft identification and orientation estimation is performed. This can be done even when the aircraft models are partially obscured from the view of the TV camera. This method, although accurate, does require that segmentation is done so that a reasonable piece of the contour is available for analysis by this program. Some effort would be required to achieve the speed necessary for real time operation of this algorithm.

A second approach to partial shape recognition was based on curvature measurements of pieces of edges extracted from 2-D images. The advantages of this method over the first is that no segmentation step is required and the algorithm requires less computation. An edge operator is used to find edge segments (not necessarily connected) that are compared to libraries of shapes. This is especially useful under camouflage situations where the true contour may be disconnected at many locations. For these contour pieces which nay be disconnected and non-ordered, sets of significant vertices are extracted. The locations of these vertices are accurately preserved by the detection process, even when the contours are extracted from medium resolution (50-100 pixel area) objects. The method used to extract these features is scale invariant. The vertex features are then rank ordered according to a significance measure and used to hypothesize matches to the library shapes. The ordering used significantly reduces the number of combinations which must be analyzed to find a match. The matching process is hierarchical in that significant vertex matches are then

followed by secondary vertex matches and finally by a tolerance band contour match. A complete description of the algorithm can be found in the Ph.D. thesis by Douglas Hung [5].

B. Orientation from Generic Shape Matching

Generic shape recognition is defined to be the recognition of an object as a member of a class of objects rather than as a specific object in a class. For example we may wish to recognize an object as an airplane or a helicopter without classifying as to specific type. In addition to recognition of category, it might be very useful to determine orientation of the airplane or helicopter for purposes of predicting its future trajectory. The advantages of generic recognition are that no specific library entry is required (that is an airplane could be recognized and tracked, even if it had not been seen before) and that the recognition process has the potential of being very fast, since no library comparisons are involved, only the matching of extracted features to a set of rules describing the generic category.

By investigating various basic structural properties of many aircraft shapes, we have found that the skeleton of the shape can most effectively be used for generic recognition. (When a human is shown these skeletons, recognition of aircraft category and orientation is usually possible). We have developed a rule based system approach to generic aircraft recognition which incorporates the following steps: (1) extract a *silhouette*, (2) reduce the silhouette to a skeleton (line drawing), (3) match straight-line segments to the skeleton, (4) label the line-segments as aircraft components according to a set of rules, and (5) use the length and angles of the labeled components to estimated aircraft orientation. Tests of this system on graphically generated aircraft (of various types) from random aspect angles have shown that 4% were incorrectly classified, 20% were labeled unrecognizable, and the remaining 76% were correctly classified with average roll, pitch, and yaw errors of under 10 degrees. Details of this technique and the results are given in the Ph.D. thesis by John Gorman [2]. Extensions of this method have been made to recognition of industrial parts for robot vision systems.

C. Representation and Comparison of 3-D Shape Data

The usc of spherical harmonics to represent 3-D objects has been investigated. Spherical harmonics date back to the eighteenth century and have been used often in the field of Potential Theory. We have looked at the possibility of using such a representation to convert range data to a 3-D model so that 3-D shape comparisons can be made. To this point we have demonstrated calculation of coefficients from range data, reconstruction from coefficient data, normalization of scale, translation, and rotation, and comparison of two shapes from their coefficient representation. This is also a viable method for matching shapes using range map data, even when the back side of the object is not visible (2 1/2 dimensional data). A complete 2 1/2 - D shape recognition algorithm has been developed and implemented which involves the matching of spherical harmonic coefficients

with library entries representing the range data expected for various viewing aspect angles. A method of scale and viewing axis rotation normalization has been developed so that shape matching can be accomplished independent of these variables. Details of this method can be found in the paper by Gorman and Mitchell [17] and the Ph.D. thesis by Gorman [2].

D. Segmentation

In this area we concentrated on improving and speeding up existing segmentation algorithms which use edge and texture data as well as developing new fast segmentation methods using model based analysis of the gray level histograms to select appropriate thresholds. The purpose of this segmentation research has been to allow us to extract the shape data from real images so that recognition and tracking can be performed.

A major problem in histogram based image segmentation is that of optimum threshold selection. We have examined the use of median filtering techniques to smooth the histogram. An algorithm has been developed which uses the root signal resulting from successive median filtering to find the major peaks of the histogram. An empirical measure was developed to test whether the histogram is unimodal or multimodal. The algorithm is very fast and provides results comparable to the iterative, discriminant, and entropy techniques with normal bimodal high contrast images. It is superior to the other techniques with respect to low contrast images and allows a user to adjust the performance by changing the separability measure [9].

In addition to threshold selection techniques, a new approach to adaptive thresholding was implemented which estimates the background statistics adaptively at each pixel based on assumptions that the low variance blocks on the border of the image are most likely background regions. The image is then segmented into regions which have labels: much darker than background, darker than background, uncertain dark, background, uncertain light, lighter than background, and much lighter than background. This technique which has shown dramatic results is discussed completely in the Ph.D. thesis by Rodriguez [4], and in the papers by Rodriguez and Mitchell [27], [28], [34], [35].

E. Tracking of Maneuvering Targets using Attitude Measurements

Video processing methods described above provide estimates of an aircraft's orientation in space. The three orientation angles can be used in a target tracker to improve tracking performance. Advanced trackers of this type utilize a mathematical model of the force system on the aircraft that is a function of vehicle attitude and velocity. The fundamental problem in target tracking is that target aircraft do not fly in straight lines during tactical situations. Rather, they will accelerate in a violent, time-varying fashion (i.e., jink) to avoid being shot down. The advantage of jinking is that the future trajectory of the vehicle becomes more

difficult to predict, making computation of the gun lead angle substantially less accurate. Lead times of 1 to 4 seconds are typical and during this period an aircraft can maneuver away from tracker gun fire. In this work, a new tracker has been developed and successfully tested in which the model of vehicle acceleration is substantially improved by modeling vehicle rotation states and by incorporating vehicle attitude measurements. Specifically, an extended nonlinear kalman filter has been designed that uses radar position and velocity information and optical attitude measurements of the aircraft being tracked. Background material on the new tracker has been published in the paper "A Nonlinear Tracker Using Attitude Information," by Andrisani, Kuhl, and Gleason [10].

Two new classes of target trackers have been developed, one for fixed wing aircraft and one for helicopters. Both new trackers used orientation data as might be provided by an optical image processor in order to substantially improve the accuracy of target trajectory predictions. Orientation was found to be useful in tracking because when a vehicle is going to turn, the first thing that happens is the orientation changes. This has the effect of tilting the lift or thrust vector that acts on the vehicle and the vehicle trajectory turns under the influence of this new force system. Because orientation always leads trajectory changes, orientation is useful in determining where the vehicle is going in the future; i.e., in predicting future trajectories. Predicting up to 5 seconds into the future is an exceedingly important part of the fire control problem since it typically takes that long to deliver ordinance from the defender to the attacker.

Our approach was to use orientation information to help determine the direction and magnitude of the lift or thrust vector and from this determine the present and future trajectory. In the fixed wing case we used orientation of the fuselage (e.g. euler angles) while in the helicopter case we used orientation of the tip path plane formed by the rotor blades as they turn above the fuselage in addition to fuselage orientation. It was found that the orientation of the tip path plane was helpful but not required in helicopter tracking because tip path angles are typically small. The orientation of the helicopter fuselage was sufficient to produce dramatic improvements in trajectory predictions.

A direct comparison of trackers using attitude measurements and trackers without attitude was initiated. Tracking software which employs attitude information was transported to ARDC in December 1986. Modification to the software was done in order to use ARDC flight data as input and to compute tracking accuracy measures in ARDC format. Comparisons with existing trackers on ARDC flight data show that the Purdue tracker achieves azimuth and elevation pointing errors 3-4 times smaller than conventional trackers that do not use attitude angles or radar rate information.

Our results indicate that the heading axis is a better axis system in which to model target accelerations then the inertial axis system. Furthermore it has been demonstrated that many of the nonlinear relationships in the mathematical model of the aircraft can be replaced by linear relationships without noticeable loss of accuracy.

Work reported in the paper "Aircraft Lead Angle Production" [12] represents a definitive comparison between trackers that use attitude and trackers that do not use attitude. Overall the improvement in trajectory prediction accuracy derived by using attitude measurements was over 300%. Research described in "Helicopter Tracking Using Attitude Information" [13] involves a first look at using helicopter body angle and rotor tip path plane angle measurements to aid in tracking maneuvering helicopters. Additional results are given in [15]. The research is continuing through other Army funding. The paper entitled "Tracker Parameter Optimization" [14] presents an analytical approach to tuning tracking filters when the target is accelerating at various g levels.

F. Other Image Processing Results

Additional results have been achieved which are related to the support provided by this contract. A significant effort has been made in development precision measurement tools, for edge location [6], [36], edge orientation [11], [26], and range [16]. Improvements in video coding have resulted [7]. Mathematical morphology methods for image analysis have been further developed [3], [18], [19], [22], [23], [30]. Techniques for visual servoing and tracking have been implemented [29], [31], [32], [33]. In addition, the techniques developed here have been applied to CAD-based inspection of manufactured parts [1], [20], [24], [2_].

III. Publications, Technical Reports, and Bibliography

The following list of publications represents work resulting entirely or in part from this grant. This section also serves as the list of references for Section II.

Theses Completed by Graduate Research Assistants
(All from School of Electrical Engineering, Purdue University, West Lafayette Indiana, Prof. O. R. Mitchell, Thesis Advisor. Those marked with an asterisk represent related research which was not supported primarily by this ARO grant).

[1]* Kirk A. Dunkelberger, "Vision for Intelligent Inspection and Assembly: Software Tools and Theory," Ph.D. Thesis, School of Electrical Engineering, May 1986.

[2] John W. Gorman, "Shape Representation and Recognition with Incomplete Information," Ph.D. Thesis, School of Electrical Engineering, May 1987

[3]* Frank Y.-C. Shih, "Image Analysis Using Mathematical Morphology: Algorithms and Architectures," Ph.D. Thesis, School of Electrical Engineering, May 1988

[4] Arturo A.Rodriguez, "Rapid Adaptive Segmentation of Images Using Successive Cost Processing,",Ph.D. Thesis, School of Electrical Engineering, August 1988

[5] Dao-Chuan D. Hung, "Shape Analysis in Low Resolution Imagery,"Ph.D. Thesis, School of Electrical Engineering, August 1988

[6]* Edward P. Lyvers, "Precision Measurements in Digitized Imagery," Ph.D. Thesis, School of Electrical Engineering, December 1988.

Other Publications Resulting from this Research

(Those marked with an asterisk are related publications but were not produced under this ARO grant.)

[7]* M. D. Lema and O. R. Mitchell, "Compression of Video Sequences Using Absolute Moment Block Truncation Coding," *1985 IEEE International Conference on Communications*, Chicago, Illinois, June 23-26, 1985.

[8] D. Andrisani, D. Gleason, F.P. Kuhl, "A Nonlinear Tracker for Maneuvering Aircraft, *Wescon/85,* November 19-22, 1985, San Francisco, CA.

[9] A. A. Farag and E. J. Delp, "Some Experiments with Histogram Based Segmentation," *Fourth Annual Conference on Intelligent Systems and Machines*, Rochester, Michigan, April, 1986.

[10] D. Andrisani, F. P. Kuhl, D. Gleason, "A Nonlinear Tracker Using Attitude Measurements," *IEEE Trans. on Aerospace and Electronic Systems*, Vol. AES-22, No. 5, September 1986.

[11]* O. R. Mitchell, M. L. Akey, K. A. Dunkelberger, and E. P. Lyvers, "Recent Results in Precision Measurements of Edges, Angles, Areas, and Perimeters," *SPIE Proceedings Vol. 730, Automated Inspection and Measurement*, Cambridge, Massachusetts, October 28-30, 1986.

[12] Frank Kuhl, Thomas Hutchings, and Dominick Andrisani, "Aircraft Lead Angle Prediction," *Eighth Annual Meeting of the Coordinating Group on Modern Control Theory*, Oakland University, Rochester, Michigan, February 4-5, 1987.

[13] Dominick Andrisani, Frank P. Kuhl, and John Schierman, "Helicopter Tracking Using Attitude Measurements," *Eighth Annual Meeting of the Coordinating Group on Modern Control Theory*, Oakland University, Rochester, Michigan, Febreuary 4-5, 1987.

[14] T. Mavromatis, D. Andrisani, and F. P. Kuhl, "Tracker Parameter Optimization," Twenty-First Annual Asilomar Conference on Signals, Systems and Computers, Pacific Grove, CA, November 2-4, 1987.

[15] D. Andrisani, J. Schierman, "Tracking Maneuvering Helicopters Using Attitude Measurements," Twenty-First Annual Asilomar Conference on Signals, Systems and Computers, Pacific Grove, CA, November 2-4, 1987.

[16] J. D. McMillen and O. R. Mitchell, "Orthonormal Fourier-Mellin transform for Precision Scale Detection and Range Data Acquisition," *SPIE Proceedings Vol 848, Intelligent Robots and Computer Vision*, Cambridge, Massachusetts, November 2-6, 1987.

[17] J. W. Gorman and O. R. Mitchell, "Shape Representation and Recognition with Depth Information," *SPIE Proceedings Vol 848, Intelligent Robots and Computer Vision*, Cambridge, Massachusetts, November 2-6, 1987.

[18]* F. Y. Shih and O. R. Mitchell, "Skeletonization by Greyscale Morphology," *SPIE Proceedings Vol 849, Automated Inspection and High Speed Vision Architectures*, Cambridge, Massachusetts, November 3-4, 1987.

[19]* F. Y. Shih and O. R. Mitchell, "Decomposition of Gray Scale Morphological Structuring Elements," *IEEE Computer Society Workshop on Computer Vision*, Miami Beach, Florida, November 30 - December 2, 1987.

[20]* R. Shoureshi, O. R. Mitchell and R. J. Cipra, "Vision-Based Intelligent Control for Automated Assembly," *ASME Winter Annual Meeting*, Boston, Massachusetts, December 13-18, 1987.

[21] J. W. Gorman, O. R. Mitchell, and F. P. Kuhl, "Partial Shape Recognition Using Dynamic Programming," *IEEE Trans. on Patt. Anal. and Machine Intel.*, pp. 257-266, March 1988.

[22]* F. Y. Shih and O. R. Mitchell, "Industrial Parts Recognition and Inspection by Image Morphology," *1988 IEEE International Conf. on Robotics and Automation*, Philadelphia, Pennsylvania, April 25-29, 1988.

[23]* F. Y. Shih and O. R. Mitchell, "Automated Fast Recognition and Location of Arbitrarily Shaped Objects by Image Morphology," *Proc. of Computer Vision and Pattern Recognition Conf.*, Ann Arbor, Michigan, pp.774-779, June 5-9, 1988.

[24]* H. D. Park and O. R. Mitchell, "CAD Based Planning and Execution of Inspection," *Proc. of Computer Vision and Pattern Recognition Conf.*, Ann Arbor, Michigan, pp. 858-863, June 5-9, 1988.

[25]* T.-C. Chang, D. C. Anderson, and O. R. Mitchell, "QTC - An Integrated Design/Manufacturing/Inspection System for Prismatic Parts," *ASME*

International Conference on Computers in Engineering, San Francisco, August 1-4, 1988.

[26]* E. P. Lyvers and O. R. Mitchell, "Precision Edge Contrast and Orientation Estimation," *IEEE Trans. on Patt. Analysis and Machine Intel.*, Vol. 10, pp. 929-937, Nov. 1988.

[27] A. A. Rodriguez and O. R. Mitchell, "Image Segmentation using Background Estimation," SPIE Proceedings Vol 1002, *Intelligent Robots and Computer Vision*, Cambridge, Mass., Nov. 7-11, 1988.

[28]* A. A. Rodriguez and O. R. Mitchell, "An Industrial Vision System for Moderately Unconstrained Conditions," SPIE Proceedings Vol 1008, *Expert Robots for Industrial Use*, Cambridge, Mass., Nov. 7-8, 1988.

[29]* J. T. Feddema, C. S. G. Lee, and O. R. Mitchell, "Weighted Feature Selection Criteria for Visual Servoing of a Telerobot," Proceedings of NASA conference on Space Telerobotics, Pasadena, CA, Jan. 31 - Feb. 2, 1989.

[30]* F. Y. Shih and O. R. Mitchell, "Threshold Decomposition of Greyscale Morphology into Binary Morphology," *IEEE Trans. on Patt. Anal. and Machine Intel.*, Vol. 11, pp. 31-42, Jan. 1989.

[31]* J. T. Feddema and O. R. Mitchell, "Vision Guided Servoing with Feature-Based Trajectory Generation," Proceedings World Conference on Robotics Research, Gaithersburg, Maryland, pp. 5-21 to 5-42, May 7-11, 1989.

[32]* J. T. Feddema, C. S. G. Lee, and O. R. Mitchell, "Automatic Selection of Image Features for Resolved Rate Visual Servoing of a Robot Manipulator," Proceedings of 1989 IEEE International Conference on Robotics and Automation, Scottsdale, AZ, May 1989, pp. 832-837.

[33]* J. T. Feddema and O. R. Mitchell, "Vision Guided Servoing with Feature-Based Trajectory Generation," *IEEE Trans. on Robotics and Automation*, Vol. 5, pp. 691-700, Oct. 1989.

[34]* A. A. Rodriguez and O. R. Mitchell, "Rapid Adaptive Segmentation by Estimation and Reassignment of Uncertainty ," SPIE Proceedings Vol 1192, *Intelligent Robots and Computer Vision,* Cambridge, Mass., Nov. 1989.

[35]* A. A. Rodriguez and O. R. Mitchell, "Image Segmentation by Background Extraction Refinements," SPIE Proceedings Vol 1192, *Intelligent Robots and Computer Vision,* Cambridge, Mass., Nov. 1989.

[36]* E. P. Lyvers, O. R. Mitchell, M. L. Akey, and A. P. Reeves, "Subpixel Measurements Using a Moment-Based Edge Operator, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 11, pp. 1293-1309, Dec. 1989.

IV. Scientific Personnel Supported by this Project:

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- Prof. O. Robert Mitchell
- Prof. Dominick Andrisani
- Prof. Edward Delp

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- J. W. Gorman (Ph.D.)
- Douglas Hung (Ph.D.)
- Edward P. Lyvers (Ph.D.)
- Dar-der Michael Chen
- Ali A. Farag
- John Schierman (M.S.)
- Theofanis Mavromatis (M.S.)
- K. L. Boyer
- D. Gleason
- E. T. Kim
- Arturo Rodriguez (Ph.D.)